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Screening wheat and other small grains for acid soil tolerance

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Abstract

Aluminum (Al) toxicity in acid soils is a major growth-limiting factor for cereal crops in many parts of the world. The most striking effect of high Al concentration in acid soils is stunting of the root system. Liming reduces Al toxicity in surface soils; however, cereal breeders must be prepared to develop cultivars that have tolerance to soil acidity. A 4 day root bioassay, originally used to identify Al toxic soils, was adapted to evaluate tolerance to soil acidity of cereal species and genotypes. Acid soil tolerance was related to the extent of inhibition of root elongation in an Al-toxic soil (pH 4.2) relative to root elongation in the same soil treated with lime (pH 5.2). Of the entries, 18% were tolerant or moderately tolerant, and 48% were susceptible or moderately susceptible when 75 bread wheat (*Triticum aestivum* L.) genotypes were tested. None of the 22 entries of durum wheat (*Triticum durum* Desf.) were tolerant or moderately tolerant, indicating much lower adaptability to soil acidity than bread wheat. The following ranking of acid soil tolerance of cereal species was obtained: rye (*Secale cereale* L.) > oats (*Avena sativa* L.) > millet (*Panicum miliaceum* L.) > bread wheat (*Triticum aestivum* L.) > barley (*Hordeum vulgare* L.) > durum wheat (*Triticum durum* Desf.). Variation in tolerance within the other cereal species was much lower than within bread wheat species. The root bioassay method is relatively quick, simple and inexpensive. The method can also be used to screen early-generation populations because assayed seedlings are still viable and can be transplanted for growing until harvest.

Introduction

Aluminum (Al) toxicity and other acid soil constraints are important growth-limiting factors for plants in many parts of the world. In fact, plant growth inhibition may result from a combination of factors including Al, Mn, and H-ion toxicities, and deficiencies of essential elements, particularly Ca, Mg, P, and Mo. The problem is particularly severe at soil pH values of 5.0 and below, but can occur at pH as high as 5.5 in kaolinitic soils (Foy, 1988; Wright et al., 1989); however, Al can also be toxic as the aluminate anion in alkaline fly ash deposits or bauxite residues at pH levels above 8.0 (Jones, 1961; Fuller and Richardson, 1986; Kinraide, 1990, 1991). Liming and other surface-applied amendments in combination with lime have a beneficial effect on these soils (Kauffman and Gardner, 1978; Wright et al., 1985; Unruh and Whitney, 1986). Recent studies (Easterwood et al., 1989; Wright et al., 1991) indicated improvements in soil chemical properties and shifts in soil solution Al speciation from toxic to nontoxic forms as a result of application of phosphate rock in acid soils of low buffer capacity.

Crop species, and genotypes within species, differ greatly in tolerance to acid soil stress; hence, cereal breeders must be prepared to develop cultivars that are genetically tolerant to high-Al soils. Although the development of crop cultivars tolerant to stress and sustainable production systems is not a new aim in plant breeding, there are also current demands for such cultivars by farmers and environmen-

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talists (Atlin and Frey, 1989; Carver and Bona, 1992). A 4 day bioassay based on seedling root elongation in soil was developed (Ritchey et al., 1988; Baligar et al., 1990) to assess chemical constraints to root growth in acid soils. Our hypothesis was that the procedure may serve as a useful tool for cereal breeders when screening a range of small grain entries for acid soil tolerance. The purpose of this study was to evaluate acid soil tolerance among and within small grain species by observing the extent of inhibition of root elongation in a toxic acid soil (pH 4.2) relative to root elongation in the same soil treated with lime (pH 5.2).

Materials and methods

Soil properties of the acidic Porters soil (coarse-loamy, mixed, mesic Umbric Dystrochrepts) used in the investigation are given in Table 1. The lime treatment consisted of adding dolomitic lime at a rate of 4 g kg^{-1} soil to reduce Al toxicity. Unlimed and limed Porters samples were analyzed for soil pH (1:1 H_2O and 1:1 0.01 M $CaCl_2$), exchangeable bases by extraction with 1 M NH_4OAc (Thomas, 1982), exchangeable Al by extraction with 1 M KCl (Yuan, 1959), clay content by the pipet method (Gee and Bauder, 1986), and organic C by combustion. Extractable Al was determined by the method of Hoyt and Nyborg (1971) (0.01 M $CaCl_2$; soil:solution 1:2). All solution concentrations of Al, Ca, Mg and K in extracts were measured using inductively coupled plasma (ICP) emission spectroscopy, except Al in 1 M KCl extracts, which was determined by titration.

The root bioassay technique consisted of germinating seeds of cereal entries (75 of *Triticum aestivum*, 22 of *Triticum durum*, 6 of *Secale cereale*, 60 of *Avena sativa*, 20 of *Hordeum vulgare* and 14 of *Panicum miliaceum*) for 1 day at 20°C in Petri dishes lined with moist filter paper. From each entry, 24 uniform, healthy seedlings were selected and planted at a rate of four seedlings per 200 ml plastic cup. Each cup contained 200 g of soil, packed to a bulk density of 1 g cm^{-3} and held at a moisture content corresponding to 33 kPa moisture tension. Three replications (three cups) of both the limed (+L) and unlimed (−L) treatments of the soil were arranged in a randomized complete block design. The cups were placed on trays containing moist paper towels and covered with a plastic dome, providing a humid atmosphere to maintain the desired moisture level. Soft, uniform spraying of the soil was done to avoid drying of the soil surface. Plants were grown for 3 days in a climatically controlled growth chamber set at 80% RH and 20°C, with 12 h day^{-1} of 115 mmol m^{-2} light illumination. The longest root of each seedling was measured at harvest, and the average longest root length (ALRL) was calcu-

Table 1
Physical and chemical properties of Porters soil

Treatment	pH		Organic C (g kg^{-1})	Clay (g kg^{-1})	Exchangeable cations (cmol kg^{-1})				Extract Al[3] (mg kg^{-1})
	1:1 H_2O	1:1 0.01 M $CaCl_2$			K^1	Ca^1	Mg^1	Al^2	
No lime	4.15	3.88	33	118	0.26	0.69	0.16	4.53	21
Lime[4]	5.15	4.70	33	118	0.25	3.04	2.57	2.26	8

[1] 1 M NH_4OAc, pH 7.
[2] 1 M KCl.
[3] 0.01 M $CaCl_2$.
[4] Dolomitic lime added at a rate of 4 g kg^{-1} soil.

lated for each replication, entry, and species (Wright et al., 1989). An acid-soil tolerance index (*Ti*) was calculated for each entry by dividing the ALRL (−L) by the ALRL(+L). Wheat cultivars with known Al tolerance were used as standards in the test. A tolerance level was assigned to each entry based on a comparison of *Ti* values with standard cultivars. Statistical Analysis Systems (SAS) programs were used to make mean comparisons among small grain entries.

Results and discussion

Ti values for standard wheat cultivars confirmed the Al tolerance classification previously described (Table 2). *Ti* of the Al-tolerant cultivar Cardinal was approximately three times higher than tolerance indexes of the Al-sensitive cultivars Hart and Arkan. On average, durum wheat entries in (−L) soil had the shortest ALRL (34 mm), whereas rye entries had the longest ALRL (91 mm). *Triticum durum* (*Ti* value 0.49) exhibited much lower adaptability to soil acidity than *Triticum aestivum* (*Ti* 0.61). However, the range in *Ti* was 1.9-fold in the durum genotypes, indicating the potential for improvement of acid soil tolerance within this species. The range in *Ti* was 3.1-fold in bread wheat genotypes (data not shown). By our classification, 18% of the screened bread wheat entries were tolerant or moderately tolerant, 34% were intermediate and 48% were moderately susceptible or susceptible to soil acidity, whereas 14% of the durum genotypes were intermediate and 86% showed moderately susceptible or susceptible responses.

Table 2
Standard wheat cultivars used in the experiment

Name, origin	Tolerance index	Al tolerance level
Yecora Rojo, Mexico	0.95	Tolerant[1]
Cardinal, OH, USA	0.97	Tolerant[2]
Becker, OH, USA	0.93	Moderately tolerant[2]
Centurk 78, NB, USA	0.65	Intermediate[3]
Colt, NB, USA	0.47	Moderately susceptible[3]
Arkan, KS, USA	0.32	Susceptible[3]
Hart, IN, USA	0.34	Susceptible[1]

[1]Ritchey et al. (1988). [2]Lafever (1988). [3]Carver et al. (1988).

The following ranking of acid soil tolerance was obtained using the root bioassay method: rye (*Secale cereale* L.) > oats (*Avena sativa* L.) > millet (*Panicum miliaceum* L.) > bread wheat (*Triticum aestivum* L.) > barley (*Hordeum vulgare* L.) > durum wheat (*Triticum durum* Desf.). The *Ti* values of rye, oats, millet, wheat, barley, and durum wheat were 1.01,

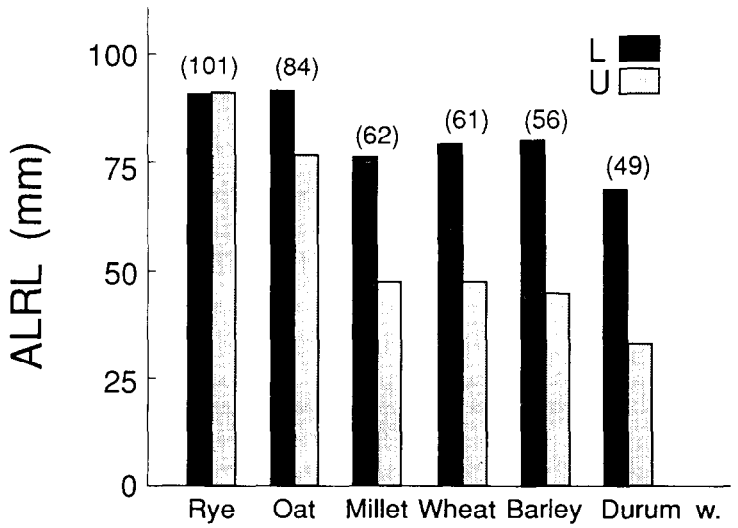

Fig. 1. Ranking of cereals for acid soil tolerance (tolerance index values are in parentheses; ALRL—average longest root length; U—unlimed Porters soil, L—limed Porters soil).

0.84, 0.62, 0.61, 0.56 and 0.49, respectively (Fig. 1). This order is slightly different from that reported by Mesdag and Balkema-Boomstra (1984), where oats were more tolerant than rye; and practically the same order was obtained by Bona et al. (1991) when a smaller size of entries was used.

The bioassay method can be useful for screening and selecting within segregating populations, as seedlings are still viable and transferable at the end of the test. The method is quick, simple, and inexpensive, and it can be a useful tool for cereal breeders. The Porters soil readily identified acid soil tolerance among and within cereal species. Any acid soil with similar characteristics could be utilized in this method. A less toxic acid soil may be more appropriate for screening entries of *H. vulgare* and *T. durum*. Nevertheless, acid soils with high organic matter content may not be appropriate media for the proposed bioassay, as organic acids in such soils can counteract toxic Al forms and alleviate Al stress symptoms. Use of acid soils with low organic matter content or culture solution techniques with different levels of Al may be of value in such cases. Tolerance to acid-soil stress differs greatly among cereal species but the genetic variability within species provides an opportunity to develop and select desirable genotypes with improved tolerance.

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